Empirical Analysis of the Use of the VISIR Remote Lab in Teaching Analog Electronics

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***Abstract*—Remote laboratories give students the opportunity of experimenting in STEM by using the Internet to control and measure an experimental setting. Remote laboratories are increasingly used in the classroom to complement, or substitute for, hands-on laboratories, so it is important to know its learning value. While many authors approach this question through qualitative analyses, this paper reports a replicated quantitative study that evaluates the teaching performance of one of these resources, the virtual instrument systems in reality (VISIR) remote laboratory. VISIR, described here, is the most popular remote laboratory for basic analog electronics. This paper hypothesizes that use of a remote laboratory has a positive effect on students' learning process. This report analyzes the effect of the use of VISIR in five different groups of students from two different academic years (2013–2014 and 2014–2015), with three teachers and at two educational levels. The empirical experience focuses on Ohm's Law. The results obtained are reported using a pretest and post-test design. The tests were carefully designed and analyzed, and their reliability and validity were assessed. The analysis of knowledge test question results shows that the post-test scores are higher that the pretest. The difference is significant according to Wilcoxon test ($p < 0.001$), and produces a Cohen effect size of 1.0. The VISIR remote laboratory's positive effect on students' learning processes indicates that remote laboratories can produce a positive effect in students' learning if an appropriate activity is used.**

***Index Terms*—Active learning, electrical engineering, engineering curriculum, remote laboratory, virtual instrument systems in reality (VISIR) remote laboratory.**

I. Introduction

SCIENCE and technology education is based on students' experimentation in a laboratory, where theoretical models are confirmed and become useful [1]. There are two main kinds of laboratories: 1) traditional or hands-on laboratories, and 2) nontraditional laboratories (NTLs) that include virtual and remote laboratories. This paper is focused on remote laboratories. In a hands-on laboratory, the student and the experimental apparatus are in the same location, while in a remote laboratory, the student is generally at a distance. For example, the experimental apparatus may be in the USA, the student in Spain, and the student's access is mediated by the Internet.

A number of books [2]–[5] and a deep review [6] describe many different types of remote laboratories. In a remote laboratory, where students use the Internet to control equipment and devices to perform an experiment, the Internet essentially functions as students' hands and eyes. This technology appeared toward the end of the last decade of the 20th century, with the first feasible results being obtained from 2000 onward; since 2010, interest has grown in the educational community. Johnson *et al.* [7] include remote laboratories in their "Time-to-Adoption Horizon: One Year or Less" category, together with learning analytics and mobile learning. Froyd *et al.* [8] include remote laboratories as one of the educational achievements of the 20th century.

There are many reasons for using remote laboratories (economic, organizational, technological, and so on), but their impact on distance learning is critical. Many universities offer online engineering and scientific degrees whose students are certified in disciplines in which laboratory work is central to the learning process. Here, administrators and policy makers rely on remote and virtual laboratories being adequate to provide the learning outcomes of the various degrees.

ABET established 13 learning outcomes for engineering [9]; these were analyzed in [10] and shown to be achievable using remote laboratories in [5], whose conclusion is similar to that of Aktan *et al.* [11], as summarized in their remote laboratory "second best to being there."

Nowadays, remote laboratories are an increasingly common teaching resource, with improving implementation, and have been analyzed from various points of view. In 2013, the benefits of using virtual and remote laboratories in the teaching and learning processes were highlighted [12]. Similarly, in the same year, the effect of using simulations and of virtual and remote laboratories was analyzed, and the conclusion reached that "both virtual and physical investigations can meet the goals for investigation in science courses" [13]. This conclusion is in line with results affirming that "the results suggest

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that remote labs are comparable in effectiveness to hands-on labs with respect to the educational objective" [14], [15].

Despite these studies, the adequacy of remote laboratories for the learning process is still under discussion with varying results being reported. In 2006, a systematic review was made of the results obtained by the different kinds of remote laboratories until 2005 [16]; some 60 studies were analyzed, and the conclusion was drawn that there was no evidence of the advantages or disadvantage of remote laboratories versus virtual and hands-on laboratories.

A similar approach, based on studies from 2006 onward, was followed by Brinson [17] who synthesized the empirical results reported in 55 published works in journals and conferences; this is the most relevant paper since 2005. Its conclusion states *"... comparative empirical studies, especially quantitative studies, are severely lacking in the literature. It is simply a matter of quantity; many more studies that directly compare student achievement of measureable learning outcomes between TL (traditional labs) and NTL, including remote and virtual labs are greatly needed. Regarding statistical methodology, these studies need to include a discussion of effect size, which was absent in the studies reviewed.*" This paper reports a new empirical study using a remote laboratory under a statistical approach based on the effect size.

This paper specifically focused on virtual instrument systems in reality (VISIR), a remote laboratory designed to experiment with analog electronics (discussed in Section II). Various researchers have examined the suitability of remote and virtual laboratories for analog electronics [18], [19], and recommended that remote laboratories should not be used in this area [20]. After some years of technical evolution of remote laboratories, this assertion was challenged [10], [21]–[24] by researchers who established the suitability of analog electronics remote laboratories from a methodological point of view.

A research question remains of whether the effect can be observed. The goal of the work reported here was to analyze the effect of using VISIR, taking an empirical approach in various contexts and academic courses. The empirical nature of this analysis is important because, as was stated in [16] and [17], the majority of reported work was based on concepts, reflections, and users' perceptions [25]–[27], rather than on empirical results and statistical analysis. An exception is a similar strategy using VISIR [23] and similar experience with a radio communication remote laboratory [28].

The results reported here will benefit not only users (students, teachers, and schools) and designers (researchers and companies), but also—and very specifically—policy makers and university administrations. Many universities offer official technical studies online, with laboratory competences being obtained using remote laboratories, so policy makers and administrators need to know VISIR is adequate for this educational purpose, as was clarified for the USA [17].

The work reported here addressed the previous research question from a statistical approach, through a pretest and post-test design. Section II provides a general description of VISIR remote laboratory. Section III describes the methodology of the study carried out in the classroom to answer the main research question, and Section IV analyzes the results obtained. Section V draws conclusions and discusses future work.

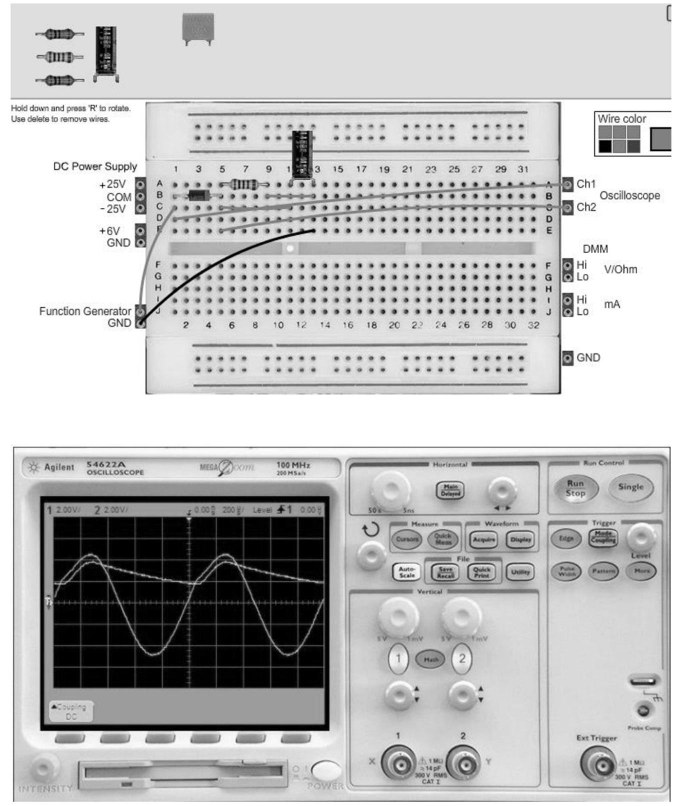

Fig. 1. Two of VISIR's elements: the breadboard and oscilloscope.

II. VISIR

The VISIR remote laboratory began in the late 1990s as a research project at the Blekinge Institute of Technology, Sweden, under the direction of Gustavsson *et al.* [29]. Nowadays, VISIR is supported by a consortium of universities in Sweden, Spain, Portugal, Austria, Georgia, and India. VISIR is mainly focused on analog electronics: Ohm's law, transistors, passive and active filters, and so on. Its design integrates very complex and expensive technical equipment (PXI and LXI technologies) with a very powerful interface based on Flash or HTML5 [22], [30].

Other remote laboratories are focused on analog electronics, such as NetLab [23], [31], RemotElecLab [32], and ISILab [33], but according to [30], VISIR is the most powerful and popular worldwide in this area (and was awarded with the "Best Online Laboratory Award" by GOLC and Global OnLine Laboratory Consortium in 2015).

VISIR includes Fig. 1 and the following:

1) a breadboard or circuit connection board (circuits under test);
2) a multimeter or tester;
3) a 6-V and ± 25-V dc power supply;
4) a function generator;
5) a two-channel oscilloscope.

In a typical sequence of use, students build their circuits on the breadboard (according to their practical exercise or experiment), power it (with ac or dc), measure it

(using the multimeter or the oscilloscope), and then analyze their results.

Of course, students cannot use VISIR to assemble an endless number of circuits; just as in real laboratories where there are limited resources, there are a certain number of devices connected to VISIR ready to be used, ten for instance, and only circuits using some or all of these ten devices can be built. For example, VISIR might provide students with four resistors, two diodes, three capacitors, and one inductor, and they can only create circuits from these elements. Note that VISIR does not simulate circuits, but builds real circuits. The technical resource used to do this is a commercial commutation matrix, or a commutation matrix designed specifically for VISIR. In either case, the use of relays is critical. The focus of this paper is not on VISIR's technical capacity and complexity, but on its pedagogic value.

One relevant pedagogic aspect of VISIR is that its significant multiplexing capacity allows simultaneous access to the laboratory, so several students can assemble and measure their individual circuits at the same time. This feature is rare among remote laboratories. VISIR can host up to 50 people at the same time, and some operational tests have even had 80 simultaneous users to test performance [22], [34]. Since teachers and students can both use the VISIR at the same time, the teaching method could be different, with practice and theory being taught together: The teacher can introduce Ohm's Law on the blackboard, and students can immediately test it using VISIR.

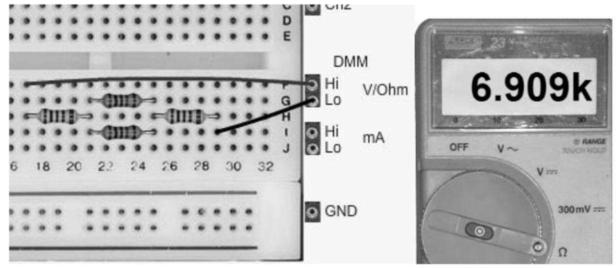

Fig. 2. Measurement of total resistance.

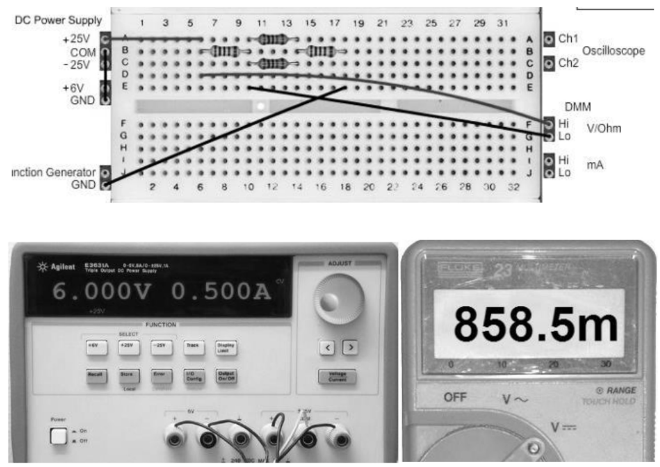

Fig. 3. Circuit, supply, and measure in dc.

III. Methodology

The VISIR educational activities analyzed here were oriented to basic electronics, in particular the connection of resistors in series and parallel, and Ohm's Law and Kirchhoff's Laws. Both these activities, described in Section III-A, can be carried out in different educational settings: secondary schools, universities, and vocational training schools.

A. Educational Activities

Two activities were carried out using VISIR in the classroom: 1) connection of resistors, and 2) Ohm's and Kirchhoff's Laws.

1) Connection of Resistors: Students have four resistors on the interface, two of 10 kΩ and two of 1 kΩ, and can connect these in any combination (series and parallel) and measure the total value of the equivalent resistor with the multimeter.

Measurements obtained from each connection should match the series and parallel mathematical models, or even better, students should be able to obtain or derive the mathematical model themselves. The teacher can decide which of these approaches to take. Fig. 2 shows a series connection of two resistors of 1 kΩ and a parallel connection of two resistors of 10 kΩ, the total value of the resistor is $1 + (10 \| 10) + 1$ equal to 7 kΩ, and the resistance measured is 6.909 kΩ, which is consistent with the theoretical value.

2) Ohm's Law: The second activity is similar to the first, but the circuits are powered and the signals to be measured are voltages and currents at different points of the circuits. Fig. 3 shows the previous circuit powered with 6 V and the voltage drop across the first 1-kΩ. resistor of 0.858 V, which is similar to the theoretical value of 0.857 V.

In the class schedule, both of these activities were carried out over two weeks with a total of 8 h class time. Two or three sessions were given to resistors and five to Ohm's Law and the corresponding circuits. Students also had to do a further 8 h of homework.

B. Research Context

The VISIR remote laboratory analysis was carried out at the Bilbao and San Sebastián campuses of the University of Deusto, Spain, and at the Urdaneta High School in Bizkaia, Spain. The experience of teachers and students was different in each of these three educational environments (see Table I), helping to generalize the results of this paper.

C. Research Question and Methodology

The research question was the following: *Does the use of the VISIR remote laboratory have a positive effect on students' learning process?*

To answer this question, a pretest/post-test methodology was used, described in detail in Section IV. The study took place over two academic years, 2013–2014 and 2014–2015. In the second year, the measurement tool (the test) was improved, and finally the results of the two years were analyzed in terms of learning effect. These are the two major results of this paper.

TABLE I
RESEARCH CONTEXT

	U. Deusto Bilbao Campus	U. Deusto San S. Campus	Urdaneta School
Subject	Physics	Physics	Physics
Weeks	2	2	2
Age	18-19 years old	18-19 years old	17-18 years old
Number of students 2013-2014 + 2014-2015	39 + 40	15 + 18	47 + 0*
VISIR Teacher's experience	User (8 years)	Expert (3 years)	No experience
Students with hands-on lab experience	YES	NO	NO

* The Urdaneta students were not involved in In 2014-2015

D. Ethical Framework

All the research guidelines of the University of Deusto's Research Ethics Committee were followed. The committee recommended that the same learning tools be used for all the students, and this recommendation was followed.

IV. RESULTS AND DISCUSSION

The main objective of the evaluation was to know if the VISIR remote laboratory had a positive, negative, or neutral effect on the learning process of students studying basic electronics.

In both courses, the study used a pre/post-test (O-X-O) design; that is, a first observation was made using a pretest of student knowledge, then two VISIR working sessions took place (without using the TL), and performance was assessed through a post-test.

Data collection was not anonymized, as this corresponded to a student learning activity, as part of their education. Data *analysis*, however, was anonymized, with the research team following the University of Deusto's ethical criteria and guidelines for data protection.

A. 2013–2014 Course

The study during the 2013–2014 course was carried out with 101 students in three different groups, enrolled, respectively, in the following:

1) a physics course on the Computer Engineering degree at the University of Deusto in Bilbao (39 students) and San Sebastian (15 students);
2) a physics course in the second stage of baccalaureate studies at the Urdaneta School (47 students).

The pretest was based on that developed in [35], with ten multiple-choice questions, P01–P10. Each question had only one correct answer. A more extensive analysis of its content validity was carried out with an improved version used in the academic year 2014–2015.

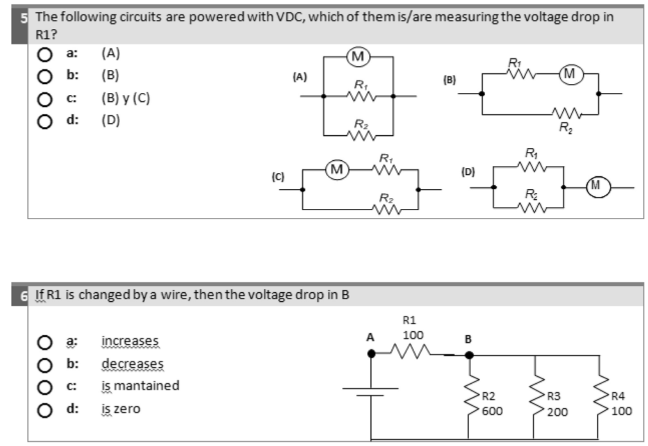

Fig. 4. Two sample test questions used in the 2013–2014 course translated into English (originals are in Spanish).

The post-test includes exactly the same questions but in a different order. Fig. 4 shows two of the questions included in the questionnaire.

A total of 188 pretests and post-tests were completed and collected, of which 87 correspond to paired data—38 in the campus of Bilbao, 14 in San Sebastian, and 35 at the Urdaneta school—so one student in Bilbao, another in San Sebastian, and 12 in Urdaneta were not analyzed.

1) Test Analysis: Before interpreting the test results, the measurement tool itself was examined to ensure the validity of its content.

The reliability of the questionnaire was determined by evaluating its internal consistency through Cronbach's alpha. The value obtained was 0.47 ± 0.07, which, even if not very high (a value greater than 0.7 would be desirable), is nevertheless significant and adequate for the purposes of the study, as the comparison is made between groups of students. The test was in any case analyzed item by item to improve it for academic course 2014–2015.

2) Results Analysis: Even though the test could have been improved, some provisional conclusions can still be drawn about the learning process with VISIR. Fig. 5 shows a box plot of the results distribution for the test before and after using VISIR. A Wilcoxon test over paired data shows that the post-test result is better than the pretest ($p < 0.001$). This improvement remains if the data of each of the three student groups is considered separately ($p < 0.01$).

B. 2014–2015 Course

During the 2014–2015 course, the learning activity was repeated with 58 students from two different groups.

1) Physics students in the first course of the Computer Engineering degree on the Bilbao campus (40 students) and San Sebastian campus (18 students). The teachers were different at each location.
2) Urdaneta School (http://www.colegiourdaneta.com/) preferred not to involve their students in the analysis in this year, so they were not included in this second study.

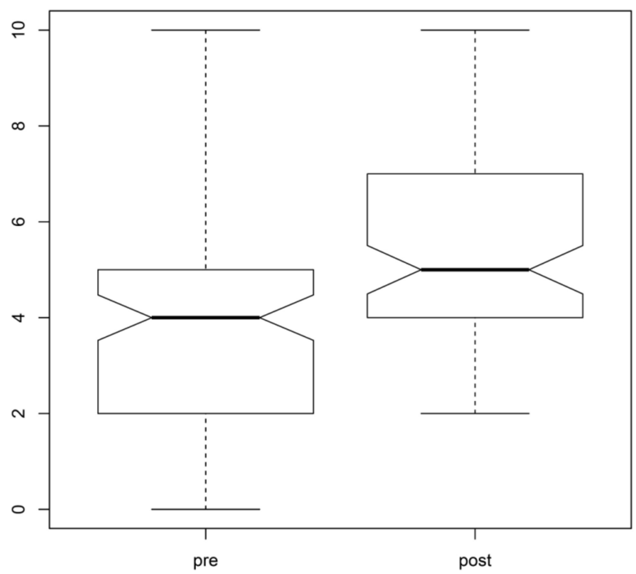

Fig. 5. Pretest and post-test results.

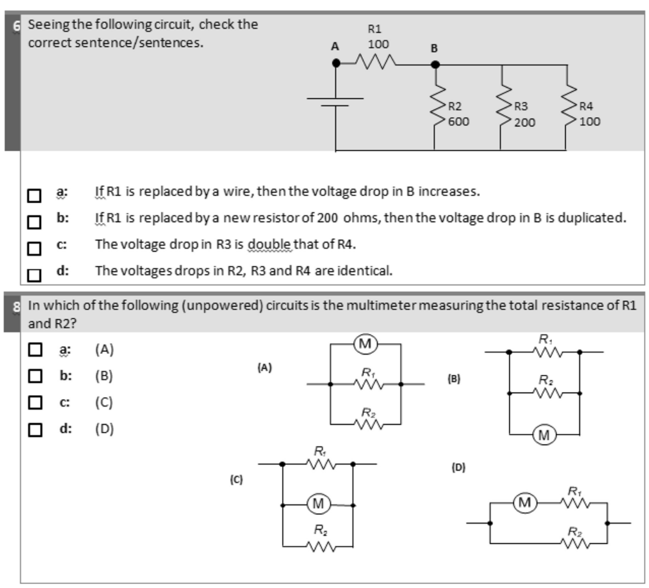

Fig. 6. Two sample questions from the test used in the 2014–2015 course, translated into English (originals are in Spanish).

The pre- and post-knowledge tests were improved from the previous course. Ten multiple-choice questions were improved and transformed into ten multiple-selection questions (in which, in Fig. 6, more than one answer can be correct). Questions identified as problematic in the previous year's study were specifically improved. The content of the new test is similar to the former one, with the original test only rearranged to give better information. In Fig. 6, the second question (#6) of Fig. 4 is reformulated with the new approach.

The tests were graded, without any correction for guessed answers, according to the correctness of each of the answers, providing 40 evaluable items.

A total of 112 completed pretests and post-tests questionnaires were gathered, including 54 sets paired data—37 students from Bilbao and 17 from San Sebastian; therefore

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
a	0.47	0.38	0.74	0.63	0.29	0.51	0.97	0.51	1.00	0.55
b	0.82	0.18	0.88	0.36	0.44	0.82	0.90	0.66	0.35	0.71
c	0.60	0.39	0.64	0.83	0.70	0.57	0.68	0.52	0.73	0.77
d	0.86	0.86	0.63	0.83	0.79	0.26	0.75	0.93	0.42	0.79

Fig. 7. Difficulty index for the knowledge test items used in the 2014–2015 course.

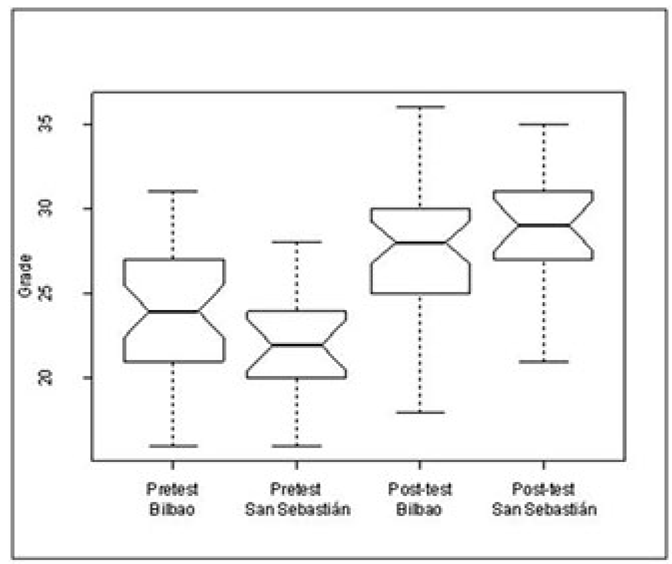

Fig. 8. Pretest and the post-test results for both student groups.

three Bilbao students and one in San Sebastian were not analyzed.

1) Analysis of the Knowledge Test: The reliability analysis of the new test gave a Cronbach's alpha value of 0.67 ± 0.05. The item analysis carried out from the results of this second test also indicated that the questions had improved when compared to the previous test.

Even when the comparison is not direct, due to the changes in number and type of evaluable items in this second test (40 elements with two options as opposed to ten elements of four options), there are items in all ranges of the difficulty index from 0.0 (maximum difficulty) to 1.0 (minimum difficulty) (see Fig. 7), which provides a better estimate of student knowledge.

2) Results Analysis: The test analysis shows that the post-test scores are higher that the pretest, to a level meaningful according to the Wilcoxon test ($p < 0.001$).

This difference remains if data from both locations is processed *separately,* Fig. 8. The statistical contrast through the Wilcoxon test confirms that post-test results are higher than the pretest in both cases ($p < 0.001$).

This difference quantified as Cohen effect size [36] gives a value of 1.0. This value is considered high in the educational literature meta-analyses and is close to the values obtained for feedback or for teachers' influence, attending to [37] and [38]. This analysis faces the future research indicated by [16].

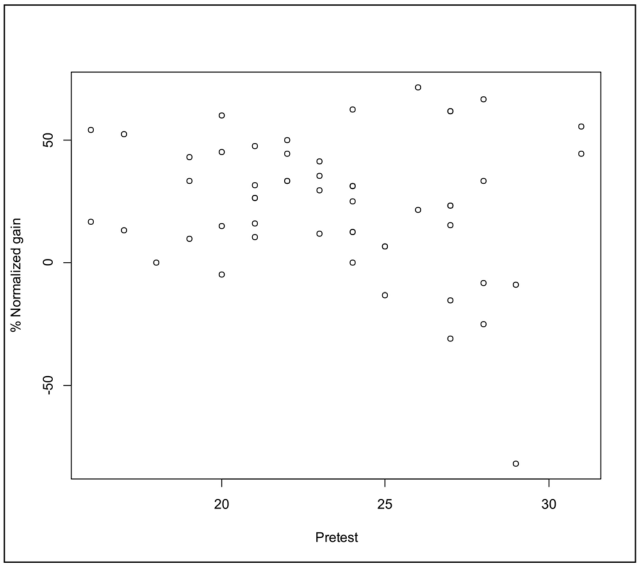

Fig. 9. Relationship between pretest and gain in terms of learning.

Finally, the effect of previous knowledge in the improvement in results was been studied. Fig. 9 shows that the normalized gain [39] does not depend on previous knowledge. This independence suggests that the use of remote laboratories favors learning both for students at a low starting level and for those with higher initial knowledge.

C. Comparison to Other Studies

A wide study was made of the use of VISIR at the university level [24], in which 1700 students had varying levels of access to VISIR with teachers who had varying levels of experience levels with VISIR usage, and varying levels of confidence in the use of the remote laboratory.

The main goal was to establish, first, why some courses and students had better performance and learning outcomes than others, and second, how to deploy VISIR in the classroom to have the highest effect on the learning process. Not all of the students involved used VISIR, only 50% of them having tried it. The average use was around three, meaning that the majority of users only built and measured three to four circuits, at most. Finally, the majority of these students combined the remote laboratory with a hands-on laboratory. In the study described here, all the students used VISIR, and only VISIR, as the laboratory to experiment with electronic circuits. In this paper, each student built and measured more than 30 electronics circuits.

To sum up, [24] presents a more general analysis of VISIR usage at university, and this paper focused on analyzing the effect of the use of VISIR in the learning process. For this last question, the results obtained in the two studies are similar, but the authors' feel the new study is more accurate in statistical terms because it only focused on one question.

V. Conclusion

The main conclusion, based on based on the use of an O-X-O design study, is that using the VISIR remote laboratory in basic electronics education helps students in their learning and has a positive effect. This conclusion is statistically significant and was valid for the five different student groups on two different courses, in three different cities, with three different teachers and two different educational levels. The variety of contexts and the strong evidence collected suggest this positive effect may hold valid for similar activities based on the use of remote laboratories.

The study also shows that detailed analysis and improvement of the test are essential to obtain meaningful and relevant results.

Future work can follow several directions. This simple study can be replicated in other educational institutions or countries using the same remote laboratory (VISIR) supported by the authors and the existing pretest and post-test. Furthermore, other remote laboratories and other subjects can be studied to confirm the value of remote laboratories as educational tools. It is also important, according to [39], to make empirical studies of the use of remote laboratories in elementary schools.

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